Sounding Cratonic Fill in Small Buried Craters Using Ground Penetrating Radar: Analog Study to the Martian Case

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SOUNDING CRATONIC FILL IN SMALL BURIED CRATERS USING GROUND PENETRATING RADAR: ANALOG STUDY TO THE MARTIAN CASE. E. Heggy[1] and P. Paillou[2], [1]Lunar and Planetary Institute, Houston, 77058-1113, TX, USA, (heggy@lpi.usraedu). [2]Observatoire de Bordeaux, Floirac, 33270, France.

We report results from a field survey performed on a recently discovered impact field in the southwestern Egyptian desert, using a 270 MHz Ground-Penetrating Radar (GPR). This hyperarid region has significant similarities to the Martian heavily eroded mid-latitude cratered terrains in terms of crater density, size, and geomorphology. Profiles across small-buried craters revealed a coherent sequence of tilted layers constituting the cratonic infill resulting from aeolian deposits. In the intercrater areas the radargram revealed a poorly defined subsurface stratigraphy and the presence of shallow structural elements associated with potential evidences of the consequences of the shock effects, i.e., faulting, fractures, and chaotic bedrock. The radar-penetration depth varied from 2 to 15 m, depending mainly on the amplitude of the volume and multiple scattering in the subsurface, caused by fractures and debris created by the impacts. We conclude that mid-frequency GPR onboard future Martian rovers can successfully perform similar structural mapping.

Introduction: Mars exhibits heavily cratered terrains in its southern hemisphere and potentially buried craters in its northern hemisphere, Its shallow subsurface is therefore likely fractured and brecciated, and heterogeneities caused by the impacts are more probably still present. Such context is very challenging for both deep and shallow radar sounding as volume and multiple scattering could dominate the attenuation in the backscattered signal [1]. While the resolution of Mars Orbital Camera (MOC) images and Mars Orbiter Laser Altimeter (MOLA) data permits the identification of larger craters and hence estimation of the potential radar clutter [2], a significant number of smaller craters, likely to be covered by the Martian superficial dust layer, may remain below the detection capability of the ongoing missions. Furthermore, high densities of small kilometer-sized craters are likely to cover a large portion of the Martian surface [3]. Such crater population may be associated with consistent heterogeneities and fractures to a depth and horizontal extent on the order of the craters diameters, producing a layer of fractured and chaotic materials that may dominate the Martian shallow subsurface in the first tens of meters, even in areas originally assumed to be crater-free and favorable for shallow probing. We hypothesize that such layers may significantly impact the ability of subsurface geophysical methods as GPR to penetrate the subsurface and distinguish the potential presence of deeper stratigraphy. On the other hand, based on the recent observations at the Schiaparelli basin, it seems possible that cratonic infill could be evenly layered and amenable to geophysical profiling or orbital sounding. Our objective therefore was to obtain profiles of analog areas on Earth to evaluate if such layering exists, and whether it can be probed using GPR.

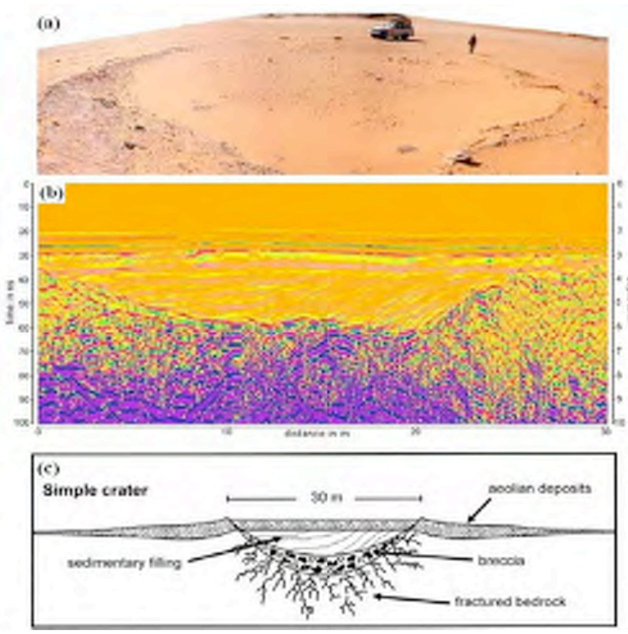

Fig.1: (a) Small-buried crater in GKCF, (b) 270 MHz profile across the buried crater, (c) interpreted model of a simple crater.

In order to address those issues, field studies are essential. The Gilf Kebir Crater Field (GKCF), recently discovered in the southwestern Egyptian desert [4], provides an optmal analog site to study the effects of a cratered environment on radar penetration depth. The site is hyperarid with no measurable annual precipitation, no vegetation cover, and no significant presence of brines or clays representing optimal conditions for conducting radar-sounding experiments.

GPR Survey Setup and Results: Radar soundings were performed using pulse repetition GPR. The system was operated with a monostatic shielded antenna configuration with a central frequency of 270 MHz and a 3 dB frequency band from ~ 220 to 320 MHz. This frequency band was selected in order to provide the best compromise between penetration depth and vertical resolution. We profiled four small buried craters (fig

1a) where we crossed the investigated structures in orthogonal directions in 30-meters-long profiles. The survey also covered an intercrater area with 900-m-long profiles in order to evaluate the horizontal extension of subsurface fractures and Grady-Kipp fragments away from the craters. Our profiles (fig. 1b) confirmed the morphology of small buried craters partially outcropping at the surface, as shown in Figure 3a. On the 30-m-long radar transect crossing the GKCF28 crater (fig. 1a), we can clearly distinguish the crater curvature, with its nearly flat bottom (due to the presence of breccias) being located 4 m deep (fig 1b), about one-tenth its diameter. This typical ratio has been observed on all four of the small craters covered by the GPR study. Figure 1b shows layered deposits (in yellow) in the crater filling. They are horizontal on the left, progressively being tilted to the right, due to deposition of the aeolian material in the downwind direction. A predominant feature on the radargram near the bottom of the crater is the fractured and brecciated bedrock that diffuses and scatters the radar signal, giving rise to the purple hyperbolic-like forms observed at 6 m depth. The sounded structures match closely the geomorphology of a simple crater as shown in Figure 1c. All four GPR profiles obtained for the buried craters revealed the same subsurface morphology: a perturbed hemispherical structure buried under sediments. Radar was unable to resolve any structure under the craters, due to the strong volume and multiple scattering in the bedrock. Figure 3c presents the interpretation of the crater structure inferred from the GPR data. In the flat intercrater area, the 900-m-long profile showed shallow structural elements associated with potential evidences of the consequences of the shock effects in the bedrock, i.e., faulting, fractures, and chaotic bedrock. While orbital and field observations in the intercrater area showed a very smooth surface, radargrams showed that there was a significant lack of stratigraphy in the first 10 m of the subsurface over the entire study area. The investigated depth was limited to a maximum of 10 m, which is lower than the instrument's nominal performance for sandy soils, due to significant losses associated with scattering.

Implications for Sounding Radar on Mars: Our results suggest two major implications for shallow subsurface sounding in Martian cratered terrains at our frequency range. The first is the ability of GPR and orbital radar to identify small buried craters, as they play a fundamental role in dating surfaces and determining the environmental and chronological evolution of Mars [5]. The 270 MHz GPR successfully probed the structural elements for the buried craters to a depth of more than 10 m and allowed to resolve the layering sequence constituting the crater filling. Both tasks can be easily achieved from a rover-mounted GPR. Therefore the lithology of the deposits that fill the craters can provide information about the climatic evolution of the study area. Tilted layering in the fill could be interpreted as aeolian sediments while parallel layers, if observed, can be associated with a fluvial filling process. Such sedimentation is already observed in high-resolution MOC images in several mid-latitude Martian craters as previously mentioned for the impact crater (located at 0.9°S, 346.2°W) in the northwestern Schiaparelli Basin [6], which exhibits a clear view of layered, sedimentary deposit. Another interesting observation we made in the GKCF is the significant difference between the number of surface outcropping craters and buried craters identified using GPR profiles: In such an arid environment, wind erosion and sand deposits tend to lower the exposed crater rims and bury them under the surface, both of which processes are representative of the Martian environment.

The second major result is the limitation of penetration depth caused by volume and multiple scattering due to the structural heterogeneity of the craters and their immediate surroundings. Despite the fact that the geoelectrical properties of the ground at Gilf Kebir are favorable to radar penetration (laboratory measured complex permittivity of 3.6 and a loss tangent of 0.004), we observed that the fractured and chaotic bedrock, a consequence of impacts, produces strong multiple and volume scattering that increases the signal attenuation and then reduces significantly the penetration depth to below the instrument's nominal value. In the heavily cratered terrain of Mars, as well as other terrain that may contain buried craters, it is clear that volume and multiple scattering in the first few tens of meters will prove to be one of the most challenging issues for high and mid-frequency radar investigations.

For lower frequencies the approach is still valid but for a kilometric scale structures. Recent results from the MARSIS 2-MHz orbital sounding radar show that the technique was able to identify large buried craters and to resolve the cratonic layering [7]. The 20-MHz SHARAD sounding radar is expected to provide similar results with a better vertical resolution and potential identification of mid-size craters.

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